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AN INTRODUCTION TO PCCS

THE PLSS COORDINATE COMPUTATIONAL SYSTEM

by
WILLIAM E. BALL, JR.

Division of Technical Services
Bureau of Land Management
Denver Service Center

March 1988

United States Department of the Interior

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Subject: The Public Land Survey Coordinate Computational System (PCCS)

The PLSS Coordinate Computational System (PCCS) is a system of computer programs which has been developed for use by experienced BLM cadastral surveyors to: (1) compute the geographic coordinates of PLSS corners using Official Cadastral Survey Record Data; (2) provide an estimate of the relative position coordinate reliability of the computed coordinates; (3) store the survey measurement data and computed coordinates in a database that can be easily accessed; (4) provide data format flexibility to facilitate data transfer to other systems that require computed coordinates of PLSS corners, such as GCDB, GIS, and ALMRS; and (5) utilize equipment that is readily available throughout BLM.

Attached are two reports that describe PCCS. The report entitled "An Introduction to PCCS" was written for BLM cadastral surveyors and for other technically-oriented personnel. The report entitled "A Brief Description of PCCS" was written for BLM personnel who might be more interested in a general description of PCCS without as many technical details.

Copies of PCCS user's manuals and other information related to PCCS can be obtained from Jon Abrams, D-433, FTS 776-0179, Commercial (303) 236-0179.

Dennis R Petersen

Associate

2 Attachments
1 - An Introduction to PCCS Report (22 pp)
2 - A Brief Description of PCCS Report (17 pp)

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AN INTRODUCTION TO PCCS - THE PLSS COORDINATE COMPUTATIONAL SYSTEM

ABSTRACT

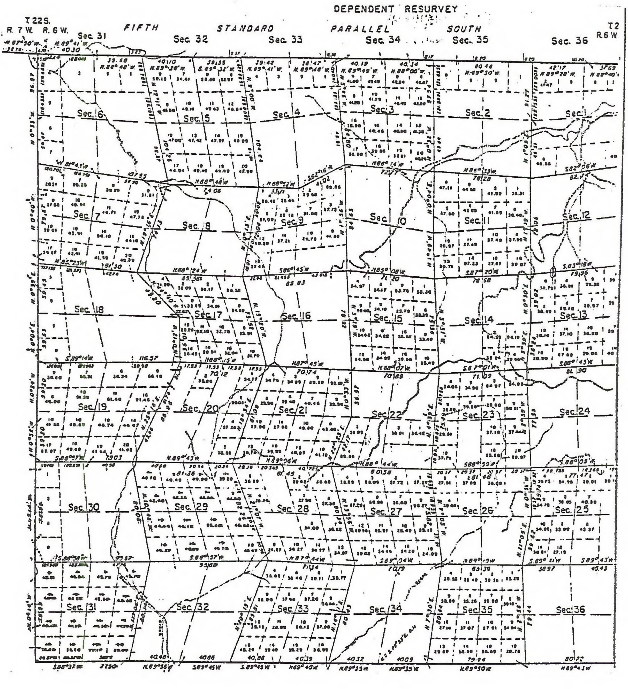
The most dependable coordinates obtainable of U.S. Public Land Survey System (PLSS) corners are needed for some applications associated with geographic information systems, land and resource records systems, map construction, map editing, map updating, computer-aided plat drafting, etc.

Unfortunately, the PLSS grid is not correctly located on some maps that are commonly used to obtain coordinates of PLSS corners employing methods such as digitizing. In addition, some features of the PLSS grid such as 1/16 corners, some 1/4 corners, and the corners of many special surveys such as river meanders, mining claims, etc. are not usually shown on maps. For these reasons the coordinates of some PLSS corners obtained by digitizing maps are not correct, and the coordinates of some other PLSS corners are not available.

To satisfy the need for a more accurate and more complete set of coordinates of PLSS corners, a system of computer programs, the PLSS Coordinate Computational System (PCCS), has been developed to (1) compute the geographic coordinates of PLSS corners using official cadastral survey record data; (2) provide an estimate of the approximate relative position coordinate dependability of the computed coordinates; (3) store the survey measurement data and computed coordinates in a database that can be easily accessed; (4) provide data format flexibility to facilitate data transfer to other systems which require computed coordinates of PLSS corners; and (5) utilize equipment which is readily available throughout BLM.

PCCS is, in effect, a functioning but still evolving system that creates a simplified geographic coordinate database (GCDB). It has been designed for use by experienced BLM cadastral surveyors.

PCCS is dependent upon the cadastral survey record and plat being an accurate representation of an actual ground survey.



Township 23 South Range 6 West as Surveyed

AN INTRODUCTION TO PCCS - THE PLSS COORDINATE COMPUTATIONAL SYSTEM

INTRODUCTION

The locations of resources as defined by coordinates can be determined with sufficient accuracy to satisfy the needs of GIS and ALMRS utilizing a variety of techniques - such as digitizing USGS maps. This is possible because some resources, such as timber stands, for example, can be photographed and mapped reasonably accurately. The coordinates of points that define the resource boundaries can then be obtained with reasonable accuracy by digitizing.

In order to determine where resources are located in relation to land ownership, the location of the PLSS grid must also be determined with acceptable accuracy in the same coordinate system as used to define the locations of the resources. Unfortunately, the PLSS grid cannot be photographed and mapped as easily and as accurately as the more visible resource boundaries. Therefore, the PLSS grid is sometimes incorrectly positioned on some maps that are used for digitizing. Map location errors of PLSS corners of one-fourth mile or more have been discovered. In addition, some features of the PLSS grid such as 1/16 corners, some 1/4 corners, and the corners of many special surveys such as river meanders, mining claims, etc. are not usually shown on maps. In such cases, the determination of resource ownership can be no more accurate than the mapped location of the PLSS grid. For this reason an accurate location of the PLSS grid is needed. (To assure compatibility between the mapped locations of the resources and the computed location of the PLSS grid the control station coordinates used for PLSS computations must be compatible with the local control station coordinates used for resource mapping).

To provide some means which utilizes existing information as much as possible for determining the geographic coordinates of PLSS corners that can be used with confidence, a system of computer programs, the PLSS Coordinate Computational System (PCCS), has been developed to (1) compute the geographic coordinates of PLSS corners utilizing official cadastral survey record data; (2) provide an estimate of the approximate relative position coordinate dependability of the computed coordinates; (3) store the survey measurement data and computed coordinates in a database that can be easily accessed; (4) provide data format flexibility to facilitate data transfer to other systems which require computed coordinates of PLSS corners; and (5) utilize equipment which is readily available throughout BLM.

The PCCS programs, some of the most significant PCCS design concepts, input data options, and output products are described briefly in the following sections.

THE PCCS SOFTWARE

The PLSS Coordinate Computational System (PCCS) consists of a set of computer programs subdivided according to their function into eight categories: (1) interactive data entry programs; (2) general geodetic traverse computational programs; (3) rectangular survey computational programs; (4) computed coordinate file creation, transformation, and utility programs; (5) special application programs; (6) PCCS graphics programs; (7) programs that link PCCS to other systems; and (8) the PCCS database program.

The programs are used independently in some cases, and in other cases several programs are used in sequence to perform a variety of computational tasks.

PCCS files and the PCCS database are organized on a township basis, and PCCS computations are performed for one entire township or for parts of one township at a time.

The information needed by the PCCS programs includes, in general, a set of accurate ground control coordinates of two or more PLSS corners in each township plus the cadastral survey measurement data that define the relative positions of all PLSS corners within the township.

Many options are provided with respect to the survey measurement data utilized, types of adjustments applied (if an adjustment is desired), and output products.

PCCS end products include (1) a PLSS Geographic Coordinate File (PGCF) which is created for each township and which contains the computed coordinates of all of the PLSS corners in the township, and (2) a PLSS Geographic Coordinate Overlay (PGCO) which is a graphic representation of the township. PGCO, PGCF and other PCCS-related file data are stored in the PCCS database where all PCCS-related information can be easily located and retrieved when needed.

Each of the eight different types of PCCS programs is described briefly in the following section.

BRIEF DESCRIPTIONS OF THE PCCS PROGRAMS

DATA ENTRY PROGRAMS

PCCS data input files are created using a set of interactive programs that request needed input data from a terminal operator, organize and format the data for later entry into one or more of the PCCS computational programs, and save the data in permanent files. The permanent data files can be edited or expanded using the same data entry programs whenever data additions or corrections are required.

Two different approaches to data entry are provided, a direct data entry approach which requires the specialized knowledge and training of a cadastral surveyor; and an optional two phase data entry approach which requires no special knowledge or specially trained personnel for initial raw data entry, but does require a cadastral surveyor to reorganize the data before it can be used.

The direct data entry approach produces a data input file in a form that is ready for use for computational purposes. The optional data entry approach can be used to produce a raw data file initially, using a PRIME computer or using a personal computer (PC) if desired. The raw data can be recorded and saved until needed. At some later time a cadastral surveyor must reorganize the raw data to produce a data input file that can be used for computational purposes. (Several State Offices are attempting to automate this process further).

Township 23 South Range 6 West as Mapped

The optional approach reduces the time required by cadastral survey personnel to create an input file since much of the data entry labor is performed by others. Raw data entry could also be performed by contractors or by BLM data entry personnel if the optional approach is employed.

Input data includes point identifiers, geographic coordinates, and elevations of ground control stations, plus cadastral survey measurement data consisting of point identifiers of surveyed PLSS corners plus the quadrants, bearings and distances between surveyed corners.

GENERAL GEODETIC TRAVERSE COMPUTATIONAL PROGRAMS

The general geodetic traverse computational programs perform three-dimensional geodetic traverse computations, compute unadjusted geographic coordinates of PLSS corners, determine traverse errors of closure, perform traverse adjustments (when adjustments are desired) and produce adjusted or unadjusted geographic coordinate files.

The general geodetic traverse programs are used for the determination of adjusted and/or unadjusted coordinates of PLSS corners along the exterior boundaries of a rectangular surveyed area and for special survey computations associated with non-rectangular surveys of water boundaries, land grants, mining claims, etc.

RECTANGULAR SURVEY COMPUTATIONAL PROGRAMS

The rectangular survey computational programs include survey measurement data evaluation programs, survey measurement data analysis programs, least squares network adjustment programs and several special purpose programs.

These programs perform three-dimensional geodetic traverse computations, compute unadjusted geographic coordinates of PLSS corners, determine traverse errors of closure, perform several different types of traverse adjustments and network adjustments (when desired), assist in the detection and location of errors, and perform a variety of special tasks - such as the subdivision of sections.

Survey Measurement Data Evaluation Programs

The survey measurement data evaluation (evaluator) programs are used to perform survey traverse computations and adjustments, and to evaluate the compatibility of survey measurement data within a township or smaller area. These programs determine (1) errors of closure in the exterior boundary of the surveyed area, (2) errors of closure between interior subdivision lines and the exterior boundary, and (3) coordinate differences at points of intersection of interior subdivision lines where two sets of coordinates are computed, i.e. at section corners where north-south and east-west section lines intersect, for example. (Adjusted and unadjusted coordinate program options exist.)

The magnitudes of the traverse errors of closure and coordinate differences at points of intersection provide an indication of the relative position coordinate consistency of the computed coordinates and/or survey measurement

data compatibility within the township. From this information a numerical reliability indicator can be selected to represent the relative position coordinate dependability of the computed coordinates of PLSS corners within the township.

The evaluator programs that produce only unadjusted coordinates evaluate the compatibility of survey measurement data only. They also provide the most conservative estimate of computed relative position coordinate consistency. The programs that perform no adjustments require no ground control. They can also be used for plat review purposes or for checking survey work.

The evaluator programs that produce adjusted coordinates evaluate the combined effects of survey measurement data compatibility, local geodetic control relative position coordinate accuracy, and traverse adjustment effectiveness.

Printed output is abbreviated and includes only the information needed for survey measurement data evaluation purposes. In addition, a complete set of adjusted or unadjusted geographic coordinate files is produced.

Survey Measurement Data Analysis Programs

The survey measurement data analysis (analyzer) programs perform approximately the same computations as the evaluator programs, but the printed output of the analyzer programs is much more extensive. Significant errors in survey measurements or in data entry can be detected and can sometimes be isolated using these programs. A complete set of adjusted or unadjusted geographic coordinate files is also produced.

Least Squares Network Adjustment Programs

The least squares network adjustment programs determine the most probable set of geographic coordinates of all of the PLSS corners within a rectangular surveyed area. The coordinates of all corners are adjusted simultaneously such that all constraints imposed upon all corners, as defined by survey measurements, are satisfied to the maximum extent possible.

Rigid boundary constraining capabilities are included to prevent changes in the coordinates of exterior boundary corners during interior adjustments. This minimizes the possibility that gaps or overlaps might be created between adjacent parcels.

Special Purpose Rectangular Survey Computational Programs

The special purpose rectangular survey computational programs perform a variety of computational tasks including area computations, section subdivision computations, determination of coordinates at points of intersection of two or more lines or parcels, etc.

COMPUTED COORDINATE FILE CREATION, TRANSFORMATION, AND UTILITY PROGRAMS

The PLSS Geographic Coordinate File (PGCF), one of the end products of the PCCS computations, contains all of the geographic coordinates that were computed by one or more of the computational programs and/or the least squares adjustment programs which were saved temporarily in files created by those programs. The computed geographic coordinate file data and coordinate reliability information are assembled by the PLSS Geographic Coordinate File

Creation Program which requests needed information from a terminal operator, reads data from other files, performs coordinate transformations to produce a set of Cartesian coordinates for graphics purposes and other special purposes, reorganizes and reformats the collected data, and creates a permanent PLSS Geographic Coordinate File (PGCF) for the township.

Because many users need the coordinates of PLSS corners in some special coordinate system other than the geographic coordinate system, coordinate transformation programs have been provided to produce PGCF files that contain UTM coordinates (in meters) or State Plane coordinates (in feet).

Also, because special forms of the PGCF files are needed for special purposes, programs have been provided to edit, sequence, eliminate duplicate records, and otherwise manipulate PGCF file data, and to create PGCF-type files using data from other than PCCS sources.

SPECIAL APPLICATION PROGRAMS

The special application programs are an evolving system of programs that currently include (1) a photogeodesy system which when completed will be used to compute the coordinates of ground control stations that are needed for PCCS computations, and (2) a system of easement and rights-of-way programs that use PCCS data and which also use some PCCS programs to perform computations needed for easement and rights-of-way purposes.

The photogeodesy system is currently being converted for use with a PRIME level A computer and is not yet operational. The easement and rights-of-way system is currently usable for straight line segments. Curved line segment computational capabilities have been developed but have not yet been added to the system.

In addition, a request has been received from a state office for the addition of a system of geometric median line computational programs.

PCCS GRAPHICS PROGRAMS

The PLSS Geographic Coordinate Overlay (PGCO) - another PCCS end product is a graphic representation of a township which resembles somewhat a cadastral survey plat. The PGCO includes all surveyed lines plus section corner annotation which consists of PCCS point identifiers, latitudes and longitudes at the computed locations of the section corners.

In the case of regular townships, PGCO files are generated automatically by programs that use the corresponding PGCF file as the primary source of information. Other PGCO files which contain information related to special surveys, such as land grants or water boundaries for example, request some additional information from the terminal operator. A program also exists which is totally under operator control that can be used to manually create PGCO files when unusual cases are encountered.

The PGCO files are used to produce PCCS graphic displays and are also used by other systems as a source of adjacent-corner-connectivity information.

PROGRAMS THAT LINK PCCS TO OTHER SYSTEMS

A primary purpose of PCCS is to produce files of computed coordinates for use by other systems. To facilitate the transfer of data from PCCS to other systems, special PCCS programs have been developed, special files are prepared by PCCS, and special programs are being developed by others to read PCCS files and transform PCCS data into a form that can be used by those other systems.

A PCCS-to-ADS program has been developed by the GIS staff to read specially prepared PCCS PGCF files that contain UTM coordinates and PCCS PGCO files that provide adjacent-corner-connectivity information. Using the PCCS data, PCCS-to-ADS creates a computed coordinate file that can be used by the GIS ADS system. A link between PCCS and the GIS system has been created in this way.

ALMRS requires a special point identifier which is entirely different from the PCCS point identifier. Therefore, to enable ALMRS to use coordinates of PLSS corners that have been computed by PCCS, the ALMRS staff is developing software that will translate a PCCS point identifier into an ALMRS point identifier. To assist in this translation, additional information needed by the ALMRS programs is stored in a special PCCS file.

The AUTOCAD graphics system provides very powerful graphics and graphics editing capabilities, and AUTOCAD is available in many State Offices. To enable AUTOCAD users to utilize coordinates computed by PCCS, a program has been developed that will create AUTOCAD files from PCCS PGCF files and PCCS PGCO files.

The US Geological Survey (USGS) has developed software that will read a PCCS PGCF file and produce a land net plate that can be used to print the PLSS grid on a USGS quad sheet. In this way, maps on which the PLSS grid has been shown inaccurately can be reprinted correctly.

THE PCCS DATABASE PROGRAM

The PCCS database (DBWEB)is an easily accessed, interactive, secure database which is used for storage, retrieval, cataloging, editing and updating of all PCCS-related files. At the present time PCCS-related files include (1) raw data files, (2) organized input data files, (3) PLSS Geographic Coordinate (PGCF) files, (4) PLSS Geographic Coordinate Overlay (PGCO) files, and (5) PCCS/ALMRS Point Identifier Translation Files.

DBWEB is a partitioned/segmented database which can accept data from all existing PCCS-related files. Other types of files (such as digitized coordinate files, control station coordinate files, etc.) could also be added to the PCCS database if a PCCS point identifier were used, and if a maximum record length of 80 characters was not exceeded.

The PCCS database program keeps track of all related township data files in the form of corresponding township file segments to provide broad cross-referencing capabilities which permits the inclusion of many different types of files containing information associated with each PLSS corner. New partitions and/or township segments can be added at anytime, which provides flexibility needed for an evolving system.

The PCCS file organization system and the PCCS point identification system are used by the database program for information storage, retrieval and location purposes.

PCCS DESIGN CONCEPTS

PCCS PHILOSOPHY

PCCS is an accurate, relatively easy to use system which has been designed for use by experienced BLM cadastral surveyors. It is intended to be a labor saving system not a substitute for knowledge or experience. Important decision options are presented and the correct option must be selected by a cadastral surveyor, as PCCS makes no important decisions automatically.

PCCS performs a wide range of cadastral and geodetic survey-related computations, some of which are relatively simple and some others are quite complex. Simple problems which also have simple input information requirements can be solved using PCCS by less experienced surveyors. More complex problems might not always have simple input information requirements. In those cases an experienced cadastral surveyor who possesses the knowledge needed to provide the input information required is expected to be in control of the computational processes and to make needed decisions.

NUMERICAL PRECISION REQUIREMENTS

Numerical precision must be a major consideration when choosing a computer for cadastral survey applications. The values of many variables used for cadastral survey purposes are expressed in terms of numerals that are ten or more significant figures in length. The longitude of a position in the western United States defined to the nearest 0.1 foot such as longitude 100° 00'00.001" when expressed in terms of degrees and fractional degrees would require ten or eleven significant figures of precision. In this example, the longitude expressed in degrees would be 100.00000028° . The same longitude in compressed degree-minute-second format, i.e., in the form 1000000.0010 would also require ten or eleven significant figures. A computer having ten or eleven significant figure precision would be required to simply read, write, store and/or retrieve numbers of this size.

If any computations were to be performed, greater precision would be required. The product of two eight digit numbers, for example, would require sixteen significant figures of precision to avoid any loss of accuracy. The product of the number 4.0000001 multiplied by itself is 16.0000008000001, a sixteen significant figure number. A thirty two bit computer might provide only seven significant figures of precision which would be inadequate for many applications. For these reasons the numerical precision characteristics of the computer to be used and the needed accuracy of the results must be known.

COORDINATE SYSTEMS FOR PLSS COORDINATE COMPUTATIONS

Coordinate systems designed primarily for mapping purposes, such as state plane coordinate systems, or the UTM coordinate system, should be avoided for large area surveys and for cadastral survey computations. Because coordinate systems of this type are distorted in relation to the earth's surface, all

angular measurements must be corrected for directional variations, and all distances must be corrected for elevation and scale variations. In addition, corrections for the effects of earth curvature and the convergence of meridians are required. All of these corrections vary with location and are, therefore, different at each point.

A coordinate system that conforms as nearly as possible to the geometry of the problem to be solved, in terms of which measurements can be most accurately and most simply expressed, and which establishes and maintains a true undeformed relationship among points, angles, and distances must be utilized for cadastral survey purposes. The natural geometric coordinate system of the earth's surface, i.e., an ellipsoidal coordinate system, should be used for applications of this type.

For these reasons, all of the PCCS programs and many other associated BLM geodetic survey and cartographic computational programs have been developed in terms of a three-dimensional ellipsoidal coordinate system, i.e. geographic coordinate system (latitute, longitude, and elevation above sea level), and in terms of three-dimensional Cartesian coordinate systems (secant space, tangent space, and geocentric coordinate systems) which can be transformed simply and directly to and from the ellipsoidal coordinate system without approximations or loss of accuracy.

When a proper coordinate system is utilized, all field measurements can be used as measured without reductions or corrections for directional orientation, elevation, scale, etc., and the effects of earth curvature, convergence of meridians, distance above sea level, etc., are properly provided for as a characteristic of the coordinate system. (Two dimensional plane survey COGO programs do not properly compensate for these types of effects.)

GEOGRAPHIC COORDINATES OF PLSS CORNERS

A multi-user, multi-purpose coordinate system must be transformable into a variety of other coordinate systems. Geographic coordinates can be transformed (using PCCS programs) into mapping coordinates such as Universal Transverse Mercator (UTM) coordinates and State Plane coordinates and can also be transformed into mathematical coordinates such as geocentric coordinates, and tangent space coordinates.

PCCS file records include geographic coordinates of PLSS corners which are stored in a one computer-word compressed 1/ degree-minute-second format that can be easily read (visually) in terms of degrees, minutes, and seconds, and can be quickly converted to degrees or radians for computational purposes or for transformation to other coordinate systems.

1/ The compressed degree-minute-second format is also used to store bearings and other types of horizontal and vertical angles.

PCCS INPUT DATA REQUIREMENTS

The PCCS computational programs utilize (1a) survey measurement data taken from plats and/or field notes of surveys that have been completed and approved in the past, or (1b) survey measurement data obtained from field notes of new or recently completed surveys; and (2) the known geographic coordinates of two or more PLSS corners within, or preferably on the exterior boundary of, the township to be processed.

Data Options

A wide range of program options are provided by PCCS with respect to the types of survey measurement data that can be utilized. Included are programs that utilize (1) true forward bearings, slope distances, and vertical angles, (2) horizontal interior, exterior or deflection angles, slope distances, and vertical angles; (3) true forward bearings, horizontal distances (at terrain elevation), and zero vertical angles; (4) horizontal interior, exterior, or deflection angle, horizontal distances (at terrain elevation), and zero vertical angles; and (5) meaned forward and reverse bearings (as recorded on BLM cadastral survey plats), horizontal distances (at terrain elevation with zero vertical angles). Also, where appropriate, instrument heights, and target heights are utilized.

The data utilized by PCCS is, in many cases, entered into a computer for the first time through PCCS data entry programs. In order to compute the coordinates of all of the PLSS corners within a township the manual entry of several hundred cadastral survey measurement data records would be required. The entry of that amount of data is time consuming. However, at the present state of the art there is no easier or faster way to enter the data needed when computed coordinates of PLSS corners are required. Fortunately, the data is entered only one time and is recorded in permanent files where it can be utilized, edited or otherwise manipulated. These data files should also be usable by other systems (such as AUTOCAD).

PCCS FILE ORGANIZATION AND FILE IDENTIFICATION SYSTEMS

PCCS files and the PCCS database are organized on a state/principal meridian/township basis, and file names include the township/range description. For example, a computed coordinate (PGCF) file for township 5 south, range 71 west of the Sixth Principal Meridian, Colorado would be identified as P5S71W. The corresponding raw data file and organized data input file would be identified as R5S71W and D5S71W, etc. The file data would be stored in PCCS database partitions reserved for T5S R71W of the Sixth Principal Meridian in Colorado.

If related data files - such as digitized data files - were also organized on a township basis (rather than on a quad sheet basis), and if a PCCS-type point identifier were used, then other types of data files could also be included in the PCCS database. In this case the PCCS database would be, in effect, a simplified GCDB.

PCCS POINT IDENTIFICATION SYSTEM

To be fully usable, a point identification system must be functional. A point identification system having mathematically logical characteristics can be sequenced, can be used for graphics purposes, possesses implicit adjacent-point-connectivity and topological characteristics, can be manipulated mathematically, etc. In addition, fixed-length point identifiers have numerous advantages over variable-length point identifiers.

PCCS utilizes a six digit, fixed-length, numerically logical point identification code for all PLSS corners which has coordinate system characteristics. The PCCS point identifiers are used by numerous other programs, other systems, and other government agencies. A point identification system which does not possess the essential characteristics described could not be easily used for some of these other purposes.

The PCCS six digit code is used to identify both PLSS rectangular survey corners and special survey corners (such as mining claims, small tracts, river meanders, etc.)

ALMRS staff personnel are developing software for translation of the six digit PCCS numeric code to the ALMRS 8-18 digit variable-length alphanumeric point identification system.

RELATIVE VS. ABSOLUTE POSITION COORDINATE ACCURACY

The computed coordinates of PLSS corners can be determined in terms of absolute position coordinates or in terms of relative position coordinates. In order to compute absolute position coordinates, the coordinates of two or more township corners must be determined in relation to the world geographic coordinate system having its origin in Greenwich, England. This can only be accomplished using existing NGS, DMA or USGS control, or using time-consuming and expensive control survey techniques. Relative position coordinates, on the other hand, can be computed using approximate geographic coordinates of a township corner obtained in some other way, such as scaling or digitizing the coordinates of the corner from a map.

The relative position accuracy of computed coordinates, in general, will depend more upon the accuracy of the cadastral survey measurement data used than upon the accuracy of the coordinates of control stations used for computational purposes.

If a user is interested only in relationships among PLSS corners within a limited area, such as within one township, accurate relative position coordinates can be used.

If a user is interested in relationships among PLSS corners that are distributed over a wider area, or in constructing maps that span several townships, a framework of control stations having accurately known coordinates that also extend over a wide area must be used. In this case the absolute position coordinates of the control stations would be needed.

Therefore, for some applications of limited geographic extent such as for plat review purposes, for example, accurate relative position coordinates are sufficient. In that case ground control coordinates might not be needed.

Ground control coordinates would be needed when the coordinates of PLSS corners are computed for the purpose of creating a PLSS Geographic Coordinate File (PGCF) that would be used for the purpose of joining together several townships in order to cover a broad area. This would often be required for ALMRS and GIS applications, for example. In general, therefore, absolute position coordinates would be required for ALMRS and GIS data files. Absolute position coordinates might also be needed for applications such as cadastral corner search activities when an absolute coordinate-based positioning system might be used to find on the ground the location of a set of computed coordinates.

VERIFICATION OF PCCS COMPUTATIONAL CAPABILITIES

PCCS computational programs employ the most up-to-date three-dimensional geodetic control survey computational techniques available. These techniques were originally developed and published by BLM, and are being taught at some colleges and universities. Identical techniques are being used by the National Geodetic Survey. These techniques have been tested extensively and successfully. The theoretical basis upon which PCCS has been developed is therefore scientifically correct.

Coordinates computed using PCCS reflect only the accuracy of the survey as represented by the survey plat. In general coordinate accuracy is neither increased nor decreased by PCCS. For this reason, PCCS could not be evaluated meaningfully using field tests as could have been used to check the results of a survey system. Instead, PCCS was evaluated by processing data having known results.

Numerous synthesized data sets having no errors and synthesized data sets having intentional errors of known location, magnitude and direction were used initially to determine if PCCS would produce results known to be correct. Subsequently real data sets were used which had known results (including data from radial surveys the plats of which show computed information rather than actual measurements, which when run through PCCS must show little or no error). In addition, numerous unadjusted coordinates computed using PCCS have been inversed to determine if the survey measurement data used by PCCS to compute the PLSS corner coordinates could be retrieved. In all cases PCCS produced correct results, or if errors occurred the causes were isolated and PCCS was corrected until all test results were exact.

NEEDED ACCURACY OF COORDINATES OF PLSS CORNERS

The accuracy of computed coordinates of PLSS corners cannot be depended upon to be any greater than the accuracy of the survey measurement data utilized by PCCS for computational purposes. An estimate of the maximum likely position coordinate error within a data set is determined by PCCS as part of the coordinate computational process. Similarly, the accuracy of digitized coordinates can be no greater than the accuracy of the maps or other material used for digitizing.

For every application requiring coordinates of PLSS corners there is, theoretically, a maximum acceptable relative or absolute position coordinate error (which must be determined by the user). A user should know, therefore, whether or not a set of coordinates that has been digitized or has been computed using PCCS is acceptable for an intended purpose.

For some applications digitized coordinates might be acceptable. For other applications coordinates computed by PCCS utilizing existing cadastral survey record data might be acceptable when digitized coordinates are not available or are not sufficiently accurate. Undoubtedly there will also be cases where computed coordinate accuracy is not sufficient when existing cadastral survey record data is utilized. In those cases a cadastral resurvey might be required to obtain greater coordinate accuracy (if the need for greater accuracy can be justified on the basis of the land or resource values involved). Increased coordinate accuracy can rarely be obtained simply through mathematical processing or by adjustment.

The coordinate accuracy needed for an intended application should govern (1) the method employed (i.e. PCCS, digitizing, etc.) to produce coordinates of acceptable accuracy for the intended application or (2) whether or not a set of existing coordinates is sufficiently accurate for the intended application.

PURPOSE AND EFFECTS OF SURVEY ADJUSTMENTS

A survey adjustment is not necessarily a correction. Under proper circumstances survey adjustments can be effective in smoothing small random errors in survey measurement data, but adjustments cannot be depended upon to correct large individual errors, blunders, or large cumulative errors. Incorrect survey measurement data and/or incorrect control station coordinates are not automatically located and replaced with correct information by an adjustment.

PCCS Survey Measurement Data Evaluation programs and Survey Measurement Data Analysis programs (which also perform adjustments) provide information (in the form of errors of closure and coordinate differences at points where more than one set of coordinates are obtained) that can be used by an experienced surveyor to isolate significant errors or blunders. The surveyor can then decide how the errors or blunders might be corrected. When blunders have been isolated, a surveyor can in some cases replace incorrect data with corrected data. PCCS does not alter official cadastral survey record data automatically.

When errors or blunders are not corrected or cannot be corrected by a surveyor PCCS can be used to (1) perform an adjustment to distribute the errors throughout a township according to a set of rules (that can be selected by the surveyor) and/or (2) to perform a least squares adjustment. In such cases the errors still exist but an attempt is made through the adjustment process to distribute the errors throughout the township. In the process of distributing the errors in an attempt to minimize their effects in the vicinity of where the errors actually exist, errors are introduced in areas where no errors existed previously. Therefore, an adjustment of data containing significant errors, blunders, or large cumulative errors might or might not produce the desired effects. PCCS always provides a surveyor with a choice of whether or not an adjustment is to be performed and, if an adjustment is desired, the type of adjustment to be applied.

For some purposes adjustments are needed. For example, adjustments are sometimes used to perform topological functions, to force a figure to close that should be closed before an area computation is performed; or to force two lines to meet at a point which should meet at a point for graphics purposes.

Least squares adjustments are frequently used to perform area readjustments of computed coordinates which have been adjusted previously using other PCCS programs that perform line adjustments. An area readjustment performs a smoothing operation that assures proper relative position relationships among section corners and adjacent 1/4 or 1/16 corners in north-south and in east-west directions.

Errors that are detected by PCCS adjustment programs are recorded as reliability indicators. PCCS reliability indicators provide a conservative estimate of the magnitude of errors that existed prior to an adjustment or after an adjustment, whichever is larger.

Traverse Adjustments By Adjustment Rule

When BLM cadastral survey traverses are run between only two stations having known coordinates, the survey measurement data frequently includes only the minimum amount of information needed for traverse computations; i.e. there are few, if any, redundant measurements. Under these conditions an adjustment can be controlled most effectively using an adjustment rule. For this reason nearly all of the PCCS programs include a specific type of adjustment rule option or a variable adjustment rule option, which permit a user to adjust angles only, distances only, or apply partial corrections to distances and angles in any desired proportion. Adjustments by rule produce line adjustments within the topographic surface.

When the survey of a township or parts of a township are treated as a network greater redundancy exists in which case least squares network adjustments can be applied (under proper circumstances).

A least squares network adjustment determines the most probable set of geographic coordinates of all of the PLSS corners within a surveyed area. The coordinates of all corners are adjusted simultaneously in such a way that all constraints imposed upon all corners are satisfied to the maximum extent possible. Least squares adjustments produce area adjustments within the topographic surface.

WEIGHTING SURVEY MEASUREMENT DATA FOR ADJUSTMENT PURPOSES

PCCS Survey Measurement Data Evaluation Programs and Survey Measurement Data Analysis Programs perform survey adjustments according to a selected adjustment rule which can take into consideration the relative quality or dependability of each survey measurement in relation to other measurements. Each measurement is assigned a numerical value, or weight, which represents the quality of that measurement in relation to other measurements. Since the quality of one measurement in relation to another is usually unknown, weighting can produce unexpected results when the weights are not, or cannot be, determined scientifically.

As an alternative to weighting each observation independently an "adjustment area" can be defined throughout which survey measurement data similarities exist such that all of the measurements within that area can be assigned a common weight. This alternative in most cases requires additional effort but usually produces more reliable computed coordinates.

INTERPRETATION OF PCCS RESULTS

PCCS is a computational or analytical system, not a surveying system. As such PCCS interprets and analyzes survey measurement data which has been recorded in terms of bearings and distances for a township or smaller area, and presents the same information in a different form, i.e. in terms of coordinates. The coordinates computed by PCCS are no more accurate nor less accurate than the survey measurement data. In the case of unadjusted coordinates the survey measurement data can be recovered from the coordinates, i.e. there is a unique and reversible relationship between the survey measurement data and the coordinates.

In addition to computing coordinates PCCS also determines how well the survey measurement data agrees with itself throughout a surveyed area. This can be done within a network such as the PLSS grid, because any point can be reached by traversing any one of numerous paths along grid lines. This provides an opportunity to determine the range of coordinate values that can be obtained at any point (or all points), which provides an indication of survey measurement data consistency or lack of consistency. PCCS records, analyzes and presents this information as a computed coordinate reliability factor. The coordinates of PLSS corners computed using PCCS are always accompanied by the reliability factor, which to a user might represent probable computed coordinate error.

A physical interpretation of PCCS computed coordinate data plus reliability factors can be described using a cadastral survey corner search analogy. To locate a PLSS corner in the field using data obtained from a PCCS PGCF file a surveyor would find on the ground the location of the PCCS computed coordinate. The surveyor would then construct a circle around that point having a radius equal to the reliability factor. The PLSS corner monument should then be found somewhere within the circle. If a large scale test were conducted a high percentage of corners should be found within the circles.

LEGAL STATUS OF COMPUTED COORDINATES OF PLSS CORNERS

The coordinates of PLSS corners have no legal status regardless of their source. Under federal law the physical evidence of the location of a PLSS corner takes precedence over any other type of corner location definition or description including coordinates.

For these and other very valid reasons the coordinates of PLSS corners are not legally acceptable for cadastral survey purposes, such as the restoration of lost corners, etc.

DETERMINATION OF COMPUTED COORDINATE RELIABILITY

It is reasonable to assume that for any application requiring coordinates of PLSS corners there will be some maximum acceptable computed coordinate error. If the acceptable error for a particular application is known and if the maximum error within a set of computed coordinates is also known, then a decision can be made with respect to the usefulness of the available coordinates for that intended application. Therefore, a conservative estimate of computed coordinate accuracy is needed before a set of coordinates can be used with confidence. (The accuracy of digitized coordinates is rarely known.)

It has been observed from numerous computations performed using PCCS that the average cumulative error in data obtained from plats of recently surveyed townships is approximately 20-40 feet. Among the most accurately surveyed townships cumulative errors of 10-15 feet are frequently found. Cumulative errors of less than 5 feet are usually found only among radial surveys, the plats of which show computed information rather than actual survey measurement data (and are, therefore, not representative of actual survey accuracy). Because most if not all of these surveys have been approved and because the errors are usually within legally acceptable limits, it is reasonable to assume that the survey measurement data is relatively free of blunders. (This assumption appears to be valid, as significant blunders are not often found using PCCS blunder detection procedures). However, because large cumulative errors still exist within the data and are, therefore, not random errors; the effectiveness of statistically based adjustments, such as least squares adjustments, is unknown and the accuracy of error analyses performed by these adjustments is also unknown.

Because an adjustment is not a correction, non-random errors that existed before an adjustment will still exist in some form after an adjustment. When large cumulative errors exist conventional statistical techniques used to determine probable magnitudes of computed coordinate error have little or no value, and survey adjustments cannot be depended upon to improve unadjusted computed coordinate accuracy. Therefore, it can only be said with any assurance to a potential user of a set of computed coordinates that when large cumulative errors exist the accuracy of the coordinates cannot be depended upon to be any greater than the accuracy of the survey measurement data and/or the relative position coordinate accuracy of the control stations used for adjustment purposes. It then becomes necessary to determine in some conservative manner the accuracy of the survey measurement data and the relative position coordinate accuracy of the control. This is accomplished by PCCS.

By examining error indicators that can be computed explicitly such as errors of closure in the exterior boundary of a township, errors of closure of interior subdivision lines with respect to the exterior boundary, and coordinate differences at points of intersection of interior lines where more than one set of coordinates can be obtained for the same corner; PCCS produces estimates of (1) possible maximum error and (2) probable error. These analyses are performed with and without the influence of external control, and both average and maximum errors are determined. The maximum value obtained is

designated the "maximum reliability indicator" which represents an estimate of the largest likely magnitude of error within the survey measurement data and/or control station coordinates. The average value obtained is designated the "average reliability indicator" which represents an estimate of the most probable magnitude of error within the survey measurement data and/or control station coordinates. These reliability indicators provide the best available information concerning the accuracy of a set of computed coordinates.

(The PCCS programs that are used to determine reliability indicators are designed to perform blunder detection analyses to locate mistakes in survey measurements. Most blunders that can be detected using conventional techniques for determining mistakes will already have been detected by a surveyor or by plat review personnel. The remaining errors that are detected by PCCS are cumulative errors that are found by examining data that extends beyond conventional closed areas).

ORIGINAL SURVEYS AND RESURVEYS

Resurveys

When the coordinates of PLSS corners are computed using record survey measurement data from recent resurveys it is reasonable to assume that those coordinates will be the most dependable that can be obtained using existing information, i.e., without additional field survey work (except for ties to existing geodetic control survey stations). It is also reasonable to assume that those coordinates will be of value for some non survey-related purposes. However, the actual dependability of the computed coordinates is usually unknown until PCCS computations have been performed.

Original Surveys

As has been stated repeatedly, the accuracy of coordinates of PLSS corners computed using PCCS cannot be depended upon to be any greater than the accuracy of the survey measurement data utilized. The accuracy of original survey data is in many cases totally unknown. In some cases hundreds of feet of descrepancy have been discovered. In other cases original surveys of very high quality have been found. In either case the quality of the survey is seldom known until PCCS reliability indicators have been computed.

More often than not when the coordinates of PLSS corners are computed using original survey record data, the ground locations of points determined using those coordinates will sometimes differ significantly from the actual ground locations of the corner monuments. (This is also true when there have been incorrect corner moves on the ground and when the coordinates of PLSS corners have been determined by digitizing maps on which the PLSS grid is not accurately located).

Fraudulent Surveys

Survey plats exist for thousands of townships throughout the western states where no surveys were actually performed or where surveys were only partially completed. Neither PCCS nor any other analytical system can be used to produce usable information from these types of surveys. Also, in many cases the fact that these surveys were never performed on the ground cannot be detected without a field inspection to determine if lines were run and corners set.

Relationship Between Original Surveys and Resurveys

A high quality original survey might agree relatively closely with a high quality resurvey. A poor quality original survey might have no relationship whatsoever to a resurvey. In general there is no predictable relationship between an original survey and a resurvey (except when the original survey was performed by one of a small number of outstanding, well known surveyors). For this reason neither PCCS nor any other analytical system can be used to produce resurvey quality coordinates using original survey data. The accuracy of the computed coordinates cannot be depended upon to be more accurate than the survey measurement data utilized.

NUMBER AND DISTRIBUTION OF CONTROL STATIONS

In order to compute the coordinates of large numbers of PLSS corners throughout a township utilizing survey record data, the coordinates of a small number of selected PLSS corners, such as two or more township corners, must be known. The coordinates of these selected corners are then used, along with the survey measurement data, to compute the coordinates of the remaining corners within the township.

The coordinates of the selected corners must be obtained in the field. This can be accomplished utilizing BLM satellite positioning techniques, photogeodesy, conventional control survey techniques, etc.

The number and distribution of control stations affects the (1) cost of computed coordinates of PLSS corners, (2) dependability of computed coordinates of PLSS corners, and (3) propagation of errors throughout a township or among adjacent townships.

Unfortunately there is no predictable relationship between the number of control stations needed and the accuracy of the computed coordinates obtained (until a PCCS computation has been performed). The accuracy of computed coordinates inevitably depends upon the accuracy of the survey measurement data. Theoretically an exact survey would require only one exact pair of control station coordinates for PCCS to produce an exact set of computed coordinates. At the other extreme there could not be enough control stations to assure exact computed coordinates in the case of an extremely poor survey.

Employing PCCS, the quality of a survey can be determined and areas where additional control stations are needed can be identified using a minimum number of high quality control stations. The number and locations of additional needed control stations can then be determined, which when PCCS is rerun should improve the accuracy of the computed coordinates.

When control station density is increased, control survey costs increase, the spacing between control stations is reduced, the detection and correction of survey errors are simplified, the effectiveness of error adjustments is improved, and error propagation can be contained within smaller areas; all of which result indirectly in increased dependability of computed coordinates (assuming that accurate cadastral survey measurement data is also available).

For these reasons the benefits of additional control vs. the cost of additional control should be considered.

For some applications, such as plat review or graphics applications, for example, relative position coordinates are sufficient in which case ground control is not needed. However, ground control is needed when the coordinates of PLSS corners are computed for the purpose of creating a PLSS Geographic Coordinate File (PGCF) for use by ALMRS or GIS.

UTILIZATION OF NAD27 OR NAD83 COORDINATES

Until recently there has been no choice as far as BLM utilization of NAD27 or NAD83 coordinates is concerned because only information based upon the North American Datum of 1927 has been available.

It is possible that at some future date BLM might again have no choice. If a national shift to NAD83 coordinates takes place, if the only available control survey data (including BLM-derived satellite positioning data) is based upon the 1983 datum, if maps used for digitizing, etc. were based only upon the 1983 datum, BLM might be forced to shift to NAD83 coordinates.

Record bearings and distances that are based upon measured ground distances and astronomically referenced directions are invariant with respect to coordinate systems. As far as PCCS is concerned, from a strictly technical point of view, NAD83 and NAD27 coordinates are equally useable. All coordinates computed by PCCS utilizing NAD83 control station coordinates would be NAD83 coordinates. Any coordinates previously computed by PCCS utilizing NAD27 control station coordinates could be relatively easily replaced with NAD83 coordinates by substituting NAD83 control station coordinates for NAD27 control station coordinates in PCCS input data sets and recomputing, provided that all final PCCS input data sets had been saved (in the PCCS database, on magnetic tapes, etc).

Existing NAD27 coordinates could also be transformed into NAD83 coordinates throughout local areas using PCCS coordinate transformation programs (if all necessary conditions were satisfied) with some loss with respect to relative position relationships. (After a transformation inversed bearings and distances between points would generally differ from record values).

USING PCCS TO COMPUTE THE COORDINATES OF PLSS CORNERS IN CURRENT SURVEYS

During the time in which the coordinates of PLSS corners within completed and approved cadastral surveys are being computed, the backlog of newly completed surveys requiring PCCS computations will continue to grow unless PCCS is used to keep up with current surveys as they progress.

Special purpose PCCS programs exist that have been developed to compute the coordinates of PLSS corners using as input field survey data in most standard forms. These programs can be used to compute the coordinates of all PLSS corners throughout small areas, such as one or two sections, or throughout entire townships.

Raw input data files can be created with small amounts of survey measurement data when a project begins, and can be continuously updated as the project continues and as new survey data is obtained; over a period of years if necessary. PCCS graphics programs can be used to create true line drawings, or can be used to create AUTOCAD script files for true line drawings or for final plat preparation.

Therefore, PCCS programs can be used for on-going cadastral survey computational purposes and for the purpose of computing geographic coordinates of PLSS corners in one operation, rather than in two separate operations which would result in an unnecessary duplication of effort.

USING PCCS AND PHOTOGEODESY TO ASSIST WITH PLSS CORNER SEARCH OPERATIONS

Very effective techniques were developed in past years that were designed to assist in finding PLSS corners on the ground. These techniques required (1) an accurate method of finding the ground locations of a given set of coordinates; and (2) a method of determining a reliable set of coordinates of the locations of the PLSS corners to be found, with an estimate of probable coordinate error.

One economical and efficient technique utilized at the Portland Service Center (PSC) combined aerotriangulation and a computational predecessor of PCCS. Employing that technique panels were placed on the ground in the general vicinity of the needed PLSS corners where they could be photographed from the air, and the coordinates of the panels were determined using the PSC Aerotriangulation System.

At the same time a set of coordinates of the PLSS corners to be found were computed, and the bearings and distances from the panel coordinates to the corner coordinates were determined. Subsequently a surveyor would go to the panel, measure the given bearings and distances to the corner coordinates and begin a corner search from that point.

A similar technique can still be used employing the DSC Photogeodesy System to determine the coordinates of the panels (or photo-identifiable objects), and using PCCS to (1) determined the coordinates of the needed PLSS corners, and (2) provide an estimate of the radii of two concentric circles surrounding the PLSS corner coordinates (equal to the PCCS reliability indicators) within which a corner search can be concentrated.

INTEGRATION OF PCCS COORDINATES WITH COORDINATES OBTAINED FROM OTHER SOURCES

Occasionally there is a need to combine coordinates obtained using PCCS with coordinates obtained from other sources. For example, the corners of groups of mining claims or tracts are sometimes needed for graphics or similar purposes where survey accuracy might not be required. In such cases the coordinates of the corners of the PLSS rectangular survey grid can be computed using PCCS, and the corners of the mining claims or tracts might be obtained by digitizing cadastral survey plats. In this case the PCCS Coordinate Integration Program can be used to adjust the digitized coordinates for integration with the PCCS-derived coordinates.

TIME AND COST INFORMATION

The Oregon State Office has used PCCS to compute the coordinates of all of the PLSS corners in nearly 270 townships. Based upon their records it has been determined that the cost of computing the coordinates of all of the PLSS corners in one western Oregon township is approximately $480. It has also been observed that under best conditions one person can complete approximately four western Oregon townships per week.

In other locations where many townships are less complex than in western Oregon the cost and time required to complete a township is significantly less. Reports of four hours per township are not unusual.

ACKNOWLEDGEMENTS

Many people in many states have contributed to the development of PCCS in many different ways. These contributions have been extremely helpful, and have resulted in improvements in nearly all existing programs and in the addition of numerous program capabilities.

SUMMARY

The PLSS Coordinate Computational System (PCCS) has been developed to (1) compute the geographic coordinates of PLSS corners utilizing official cadastral survey record data; (2) provide an estimate of the approximate relative position coordinate dependability of the computed coordinates, (3) store the survey measurement data and computed coordinates in a database that can be easily accessed; (4) provide data format flexibility to facilitate data transfer to other systems which require computed coordinates of PLSS corners; and (5) utilize equipment which is readily available throughout BLM.

PCCS is, in effect, a functioning but still evolving system that creates a simplified geographic coordinate database. It has been designed for use by experienced BLM cadastral surveyors.

PCCS is dependent upon the cadastral survey record and plat being an accurate representation of an actual ground survey.